Enallagma civile (ODONATA: COENGRIONIDAE) LIFE HISTORY AND PRODUCTION IN A WEST TEXAS PLAYA

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A life history and productivity study of *Enallagma civile* was conducted in a playa that was located in the Southern High Plains of Texas. Other odonates were also studied to identify their contributions to the habitat.

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CHAPTER 1

INTRODUCTION

Playas

Playas are ephemeral water bodies and are filled by rainfall and surface runoff. Water is lost by evaporation and by some percolation into the ground water. The evaporation and percolation are a small amount due to the clay and rock layers that underlie the playas (Rosen 1994). It is believed that playas are formed when precipitation puddles and then carbonic acid is formed from decaying matter thus dissolving carbonates and causing enlargement of the puddle (Osterkamp and Wood 1987).

There are approximately 50,000 playas on earth (Rosen 1994), about 30,000 occur in the Southern High Plains of North America (Wood 1987), and more than 19,000 of these occur on the Texas High Plains, which is also known as Llano Estacado (Figure 1) (Texas Parks and Wildlife 1995). In the Southern High Plains, playas may occur as often as once per 2.6 kilometers (Haukos and Smith 1997). Playas of the Llano Estacado typically fill during the late spring, summer or fall ( ). Normally, they are dry during the later days of winter and the early days of spring. The basins are small, usually less than a few kilometers with an average depth less than four meters (Wood 1987).

In the Llano Estacado, rainfall is highly variable and therefore playas are variable in their occurrence and duration. This semi-arid region has an annual precipitation less than fifty-one centimeters and constant winds produce high evaporation rates (Panhandle-Plains Historical Museum 1999). The Texas panhandle, also known as the "buffalo prairie", has wind speeds that are between 15.7 and 16.8 miles per hour (Carson County)

(Panhandle-Plains Historical Museum 1999). Some playas have been modified for irrigational or agricultural purposes and never completely dry up.

The Texas High Plains are composed of millions of acres of flat, treeless grassland. Playas serve as a major water resource for this featureless land. They are used by farmers for irrigation and animals for habitat. There are many plants and animals associated with playas in Texas. Modified playas that retain water often serve as overwintering sites for waterfowl such as the long-billed curlew, American avocet, killdeer, Mississippi kite, mountain plover, lark bunting, American kestrel and the bald eagle (Texas Parks and Wildlife 1995). There are in addition, at least thirty-seven species of mammals associated with playa lakes and numerous reptiles (Haukos and Smith 1987). Playas are also habitable to eighty-six species of plants in the Southern High Plains alone (Texas Parks and Wildlife 1995). In 1996, Kennedy et al. identified over 80 macroinvertebrate taxa; mostly insects (nearly 90% of the total) were identified from playas on the Southern High Plains of Texas.

Playa Odonata and *Enallagma*

Odonates (Insecta), also known as dragonflies and damselflies, are found around the world. There are nearly 2,500 species of dragonflies and nearly 2,500 species of damselflies that have been identified (Corbet, 1999). In North America alone, there are nearly 650 species of Odonates (Merritt and Cummins 1996). Odonates are hemimetabolous organisms that can be found anywhere from acidic bogs to holes in tree trunks. Most dragonflies and damselflies are aquatic as juveniles and live terrestrially as adults but near water bodies. Dragonflies are placed in the subphylum, Anisoptera while damselflies make up the subphylum, Zygoptera. Playas in the Southern High Plains are represented by four of the twenty-one Odonate families: Aeshnidae, Libellulidae, Coengrionidae, and Lestidae (Kennedy et al., 1996). Odonate representatives in the playas of the SHP include *Anax junius* (Drury, 1770) (Aeshnidae), *Sympetrum corruptum* Hagen, 1861) (Libellulidae), *Tramea onusta* (Hagen, 1861) (Libellulidae), *Lestes disjunctus* (Selys, 1862) (Lestidae) and *Enallagma civile* (Hagen, 1861) (Coengrionidae) (Kennedy et al., 1996).

Enallagma civile is the dominant Odonate of these playas. It is commonly known as the familiar bluet damselfly. The genus *Enallagma* (Charpentier, 1840) has been described by noting several key characteristics. Damselflies of this genus are noted as having bright blue and black colors. Females are less obvious than the males because their colors are not as vivid. *Enallagma* sp. are numerous in a variety of aquatic environments but are most abundant where vegetation abounds in still, shallow, fresh water although they may be found around brackish water or desert alkaline pools (Betnick et al., 1968). The species, *Enallagma civile*, was first described by Hagen in 1861 and has a ubiquitous distribution in North America (Figure 2) (Westfall and Minter, 1996).

Odonates may be known by many names such as "darning needles", "devil's darning needles", "horse stingers", "mosquito hawks", "snake feeders", and "snake doctors" (Clausen 1954). The adults are predators, capturing their prey on wing. They prey on mosquitos and other flying insects. The naiads are also predatory and have a labium that is modified for this lifestyle. It is formed into a spoon-like apparatus that may be shot forward to capture unsuspecting prey. Odonates spend anywhere from thirty days to five years in the naiad stage before emerging as adults (Miller 1987). In this time, the naiad may go through ten to twenty instars. Prior to this, they exist as eggs for one to three weeks. These eggs are usually in submersed macrovegetation (Miller 1987). “Its [the egg’s] duration in the plant depends partly on altitude and latitude” (Miller 1987).

Eggs are laid after the female is fertilized. The male grasps the female behind the head with the end of his abdomen and together their bodies form a “wheel position”. He then delivers his sperm packet, or spermatheca, to the female’s genitalia. She then will find a place to oviposit. This oviposition site may be in the tissue of any surrounding vegetation. Her egg clutch may contain more than 200 eggs (Zehring et al 1962). The male may accompany her to the oviposition site thus insuring no other suitors attempt to mate with her. He may even force her underwater to oviposit.

Aquatic vegetation is crucial to Odonate populations for reproduction since they are endophytic egg-layers. In addition, Odonates as juveniles use aquatic plants for anchorage, concealment, foraging, and site defense. As adults, Odonates use aquatic macrophytes for emergence support, basking, copulation, foraging, nocturnal roosting, territorial boundaries and behavior, shelter and habitat selection (Buchwald 1992). Four other species besides *Enallagma civile* were captured and studied in the playa setting. These Odonates are *Tramea onusta*, *Sympetrum corruptum*, *Anax junius*, and *Lestes disjunctus*. Theses species were all studied in order to understand Odonate life histories and productivity in playa habitats.

The genus *Tramea* has seven described species in North America. Members of this genus have a widespread distribution from Canada and the U. S. south to Panama and the West Indies (Usinger 1968). *Tramea* naiads are predatory engulfers that may be found sprawled among aquatic macrophytes in lentic and lotic habitats (Merritt and Cummins 1996). They may also be found crawling through trash and silt near shorelines of warm quiet ponds and lakes (Usinger 1968). Adults may be distinguished by a brown mark across the base of the hindwing (Usinger 1968).

Another playa Odonate, *Sympetrum corruptum*, is part of a genus in which there are 15 described species in North America. It is also widespread in its distribution. The naiads of this genus may be found sprawled on or climbing upon aquatic plants and detritus in ponds or wet meadows (Usinger 1968). The adult *Sympetrum* sp. are reddish in color and are frequently found in plentitude in sunny habitats. These adult dragonflies are most abundant in the autumn and are noted as being poor fliers and easy to capture (Usinger 1968).

Anax junius, the green darner dragonfly, is one of three described species of the genus *Anax* in North America. It is very common in North America, especially in the far North and the far South. *Anax* naiads climb on vascular hydrophytes and stalk their prey. These brown and green juveniles are found in lentic habitats and are notoriously cannibalistic (Usinger 1968). They may even capture and engulf small fish. The adults are very large and strong fliers (Usinger 1968). They are often mistaken for small birds.

The last Odonate, *Lestes disjunctus,* is a damselfly that is one of sixteen damselflies in the genus *Lestes*. The species is found throughout North America north of Mexico (May and Westfall). Members of the genus, *Lestes*, are climbers and swimmers as juveniles. They may be found in lentic and lotic habitats on aquatic plants (Merritt and Cummins 1996). Adults are slow flyers and may be found at the margins of ponds, bogs, marshes, or other areas where vegetation is above the water surface (Usinger 1968). They fly low and rarely fly over open water (Usinger 1968).

Most Odonates do not have a life stage that can survive droughts in an aquatic habitat. They either emigrate by flying to a new habitat or oftentimes, the juveniles and eggs just dry up along with the water body. The damselfly, *Lestes disjunctus*, and its eggs have been known to survive in the plants in which they were oviposited in (Corbet, 1999). Juveniles of the species *Tramea onusta*, *Sympetrum corruptum*, *Anax junius*, and *Enallagma civile* eggs do not have the ability to survive when playas dry up (Corbet 1999). These Odonates populate playas after they have migrated from a more permanent water body. This might include cattle tanks or drainage ditches. Adults of *Enallagma* sp. have been found as far as 2.7 kilometers from their site of oviposition in lakes (McPeek 1989). Odonates are often carried to other playas by the wind and therefore known as aerial plankton (Watson 1981). After the playas flood, the naiads emerge as adults and venture to playas to oviposit. By colonizing these ephemeral water bodies, the Odonates are able to maximize their predatory lifestyle and with less chance of becoming prey themselves.

CHAPTER 2

RESEARCH OBJECTIVES

The purpose of my research was to describe the odonate population in a west Texas playa wetland. *Enallagma civile* was the most numerous odonate of the habitat and the focus of my research. Other odonates included *Tramea onusta* (Libellulidae), the variegated meadowhawk, *Sympetrum corruptum* (Libellulidae), the red saddlebags dragonfly, *Anax junius* (Aeshnidae), the green darner dragonfly, and *Lestes disjunctus* (Lestidae), the spreadwing damselfly. For *E. civile* as well as for the other odonates, specific objectives included determining the abundance, developmental rates, and secondary productivity if enough individuals of each species were available. Odonates are major keystone predators in playas and are valuable components of the playas. Previously, little ecological research has been conducted on invertebrates in the playa setting and there are few publications including any odonate data from a playa lake.

CHAPTER 3

STUDY SITE

The original playa lake samples were collected on government owned property known as the Pantex Plant just northwest of Amarillo, Texas. The facility had been the location for military weapons assembly, storage, and dissassemblament since the 1940's (Kennedy et al 1996). The facility is approximately 10,000 acres in size and contains several playas. The original playa samples were collected through a study funded by the U. S. Department of Energy to evaluate species composition and diversity of two playas just outside the Pantex Plant and six on-site playas (Figure 15). One out of the six on-site playas was chosen for my study site. It was chosen because it retained water the longest out of the six on-site playas. The samples were collected from June of 1995 through September of 1995. For my research, samples from the study playa, which is on the Pantex Plant, were taken once every two weeks. This playa first flooded in June 1995 after it had been dry for two years. It filled after increasing rains occurred during late May and early June. When this water body filled, it encompassed approximately 40 hectares and had a maximum depth of one meter (Kennedy et al. 1996). From June through early September, due to a lack of rains and evaporation the water in Playa 2 became reduced thus decreasing the depth and area until only isolated pools existed (Kennedy et al. 1996). Playa two receives storm runoff waters. Rarely, treated wastewater empties into a ditch that runs into the playa. Playa two has a watershed that encompasses approximately 1,113 hectares. The watershed is comprised of about ten percent industrial usage, thirty-two percent cultivated land, and twenty percent grassland.

Obvious modifications to the floor of the playa did not exist at the time of sampling (Kennedy et al 1996).

Playa Two had several types of aquatic vegetation that inhabited its waters or its banks. These macrophytes included smartweed (*Polygonum* sp.), common arrowhead (*Sagittaria latifolia*), and bullrush (*Scirpus* sp.). Some of these plants surrounded the banks of the playa whereas others were more toward the innermost portion of the playa. This vegetation is important to mention due to the fact that many Odonates are endophytic egg-layers.

Odonate naiads were collected on May 5, 1999, for research from a playa that was not located on the Pantex Plant. The samples were collected on privately owned land with permission from the landowner. The property was located at the intersection of East Hollywood Road and South Whitaker Road, which can be reached by traveling on East Loop 335 South Road. The property was used during the growing season for growing alfalfa.

CHAPTER 4

METHODS AND MATERIALS

Physico-chemical Parameters

During the course of the original Department of Energy study in which the first Odonate samples were collected, different water quality measurements were taken. These included temperature, dissolved oxygen, pH, chlorophyll *a*, turbidity, and specific conductance, which were all taken monthly (figure 3).

Collection Methods

The playa was divided into and sampling was randomly selected from eight sectors: N, NE, E, S, SE, W, SW, NW. Odonate naiads were collected after four plywood panels were placed into the water to form a one-meter squared frame (figure 16). An aquatic sweep net (approximately 250-350 um mesh, 30 cm. width) was used to make the depletion samples which consisted of sweeping the entire area of the frame. Each sweep was taken after the net was placed on the bottom of the playa and swept through the vegetaion forwards and backwards. This motion was completed 2 times for a total distance of 1.25 meters. The sweeping or depletion sample was completed four times with a total distance sampled of five meters (Kennedy et al. 1996). The samples were fixed and preserved with Kahle's solution and later were transferred to an eighty-percent ethanol solution for long-term storage.

Density of the Odonate Populations

The density of the Odonate populations was based on the catch-per-unit effort theory. This theory relates depletion samples to a population size regression. With each depletion, the population size should decrease and each depletion should have fewer and fewer numbers of organisms captured. Based on these depletions, a negative regression can be constructed and a population size per m^2 may be estimated (Maciena et al. 1993, Mahon 1980, Zippin 1958). A program entitled Microfish was developed to estimate population sizes based on these regressions and was used in this study to estimate population sizes. This negative regression will show a decrease in population size as time passes. The program was developed for fish studies in fisheries but it is just as applicable with insect populations (Carle 1976, Carle and Strub 1978). For each sampling date and each zone in the playa, the program calculated an estimated population size per m^2. Since there were three zones per sampling date, it was necessary to take the mean of these three average population sizes to get the average population estimate per m^2 for each sampling date. (Figures 9,10,11,12 and 13)

Size Class Analysis

Odonates do not have obvious instars and therefore an alternate means of size classification was used. The naiads were measured by their head capsule widths in millimeters or centimeters based on the size of the organism. *Lestes disjunctus* and *Enallagma civile* were measured in millimeters whereas *Tramea onusta*, *Sympetrum corruptum* and *Anax junius* were measured in centimeters due to their larger size. All Odonates were measured at the widest point of their head capsules which was across the tops of their heads between their eyes. This method of measurement had previously been used in other studies using Odonates (Benke 1979). The Odonates were viewed and measured using the Olympus™ Cue-2 Image Analyzer and an Olympus SZH dissecting microscope. After the measurements were taken, the dragonflies were placed into several size groups. *Tramea onusta*, *Sympetrum corruptum* and *Anax junius* were placed in size groups based on half-centimeter groupings whereas *Lestes disjunctus* and *Enallagma civile* were placed in groups of half-millimeters. These groupings were done in an effort to show size changes of the different organisms over time.

For the species *Enallagma civile* , a regression line was constructed to show the relationship between head widths and dry weights. This line was also constructed to aid in calculating secondary productivity. Thirty-nine live naiads of *Enallagma civile* were captured and placed on aluminum foil trays. These damselflies were dried for twenty-four hours at 105 ^{o}C. After drying in the oven, the naiads were placed in a dessicator for twelve hours to ensure dryness. The damselflies were weighed using a Cahn^{TM} microbalance (Table 1).

Greenhouse Growth Studies

Growth studies were conducted in order to estimate the number of degree days needed to rear an Odonate egg to the adult stage. An enclosure was constructed of PVC, a fine mesh screen, and velcro. Its dimensions were 1.3 meters high by 1.3 meters wide by two meters long (figure 17). The velcro was used to hold the plastic mesh to the PVC, yet allow for easy entry into the enclosure. This enclosure housed a fiberglass tank that was one meter by .33 meter by .5 meter. The fiberglass tank was used to hold dechlorinated tap water and aquatic plants. It held approximately 22.5 gallons of water when it was filled. The aquatic plants were brought back from the study area in Amarillo, Texas, after they had been observed to be oviposited in by *Enallagma civile*.

The plants included arroweed (*Sagitaria* sp.), pondweed (*Potomogeton* sp.), and smartweed (*Polygonum* sp.). Each plant was removed with its original sediment intact and placed in plastic containers. These containers were placed in an ice chest and then brought back to the greenhouse at the University of North Texas. Once the plants were deposited in the enclosure, they were left alone with the exception of water additions to replace water lost due to evaporation. An Onset^{c} data logger was added to record temperatures hourly in ^{o}C. Daily greenhouse temperatures were used to calculate an average greenhouse temperature. From daily greenhouse temperatures and the average greenhouse temperature, the total degree days for *Enallagma civile* were calculated. The fiberglass tank was checked daily for naiads and adults of *Enallagma civile*.

CHAPTER 5

RESULTS AND DISCUSSION

Physico-chemical Parameters

The temperature taken was that of the playa water and it is important to show fluctuations in conditions of the playa. Dissolved oxygen (DO) is an important to measure because it is changed by amount of wind, by photosynthesis, and by the amount of biological oxygen demand (BOD). The pH is also affected by the amount of photosynthesis and in addition by rainfall and the lack of rainfall. Cholorphyll *a* can demonstrate the amount of phytoplanktonic biomass (Wetzel 1983) which is important in determining food web dynamics. Another measurement taken, turbidity, is important because it shows the amount of dissolved and suspended matter in the water column. Turbidity affects the amount of light that can pass through the water column and thus changes the amount of autotrophic energy. The last measurement to be measured was the conductivity of the playa water. Conductivity was taken with a specific conductivity meter and it shows the amount of ions in the water. During the time between June and September, morning air and water temperatures were about 20^{o} C. Mean daily temperatures for this area range from 1-3^{o}C in the winter to 25-28^{o}C in the summer (Kennedy et al. 1996). Water temperatures had a range of 18.3^{o}C at 0930 h to 29.4^{o}C at 1630 h on 2 September 1995 (Kennedy et al. 1996). Annual frost-free days range from 180 to 220 (National Weather Service). The pH was usually in the neutral range (7.0). The range of conductivity was between 250 and 340 micromhos/cm in June and September respectively (Kennedy et al. 1996).

Populations and Development

Average nymphal densities for all of the sampled Odonates, *Enallagma civile*, *Tramea onusta*, *Anax junius*, *Sympetrum corruptum*, and *Lestes disjunctus*, were all zero on the first sampling date, June 7, 1995. During this period the playa had filled and Odonate colonizers were just beginning to colonize the playa. The first Odonate to colonize in the playa was *Enallagma civile*. On June 28, 1995, early instars of E. civile were collected in Playa 2. This event is not suprising due to the fact that Enallagma civile has been noted to be one of the earliest colonizers to new water bodies (Walker 1953; Dunkle 1990). Other Odonates began to appear in sweepnet collections made on July 22, 1995 (Figures 9,11,12, and 13). After this date, the five Odonate species densities began to increase. On August 18, 1995, however, all of the Odonates suffered a severe population decrease. This trend was due to the playa losing a major amount of water due to evaporation and a lack of rain events. About ten days later, the playa began to fill again with rainwater and runoff. After the playa refilled, the *Enallagma civile* and the *Sympetrum corruptum* populations stayed fairly low in their densities with little increase in population size. The *Lestes disjunctus* population nearly doubled and the Anax junius population density increased five-fold above the August 18, 1995 sampling date. *Tramea onusta* had the only population density that continued to decrease after the playa refilled. Its population size dwindled to nearly 25% of what it had been on August 18, 1995.

In addition to the actual larval densities, the Odonates were classified by estimations of the total larval densities per m^2. These population estimates were calculated using the program Microfish. According to population estimates using Microfish, *Enallagma civile* was the first population of Odonate to exist. This damselfly was estimated to show up on June 28, 1995 with an average population size per m^2 of about 150 naiads. *E. civile*'s population was estimated to have peaked on August 12, 1995 with an average population estimate per m^2 of a little less than 750 naiads (Figure 7). This estimate was the highest of all Odonate populations. *Tramea onusta*, *Anax junius*, *Sympetrum corruptum*, and *Lestes disjunctus* began population growth according to Microfish on July 22, 1995 and continued to grow in population size until August 4, 1995. *Tramea onusta* peaked in its average population estimate per m^2 with about 35 naiads on August 4, 1995. *Sympetrum corruptum* and *Lestes disjunctus* also peaked on this date with about seven and three naiads per m^2 respectively. *Anax junius* populations peaked on August 4, 1995 and then its population size estimate decreased but then increased again to its highest peak of about twenty-eight naiads per m^2 on September 2, 1995.

Populations of Odonates were also described by the sizes of their head capsule widths. These measurements were completed to show changes in development over the sampling period. Size classes were constructed based on these measurements. The smallest size class would include the youngest and smallest dragonfly and damselfly naiads. The gills of the zygopterans are threadlike and hairy and the eyes of the dragonfly and damselfly naiads are light in color. Wingpads are non-existant or are very miniscule. As the size classes increase, the Odonates become larger and the wingpads become larger and more pronounced. In the zygopterans, their caudal lamellae become more triangular as they age (Miller 1987). In the last and largest size class, the Odonates are at the size where they are almost ready to emerge. There is a darkening of the eyes and the wingpads.

In Playa 2, *Enallagma civile* first appeared on June 28, 1995. On this date, organisms captured were all in early developmental stages. These naiads were all under 0.49 mm. It is estimated that they were all oviposited a week within their capture. On July 22, 1995, naiads were captured that were in the largest size class, 3.0-3.49 mm. This is the size class that contains naiads that are just about to emerge as adults. Due to these samples, it is possible to estimate the amount of time *Enallagma civile* took to emerge as an adult from a hatchling. It is roughly three weeks. This estimate is not different from previously recorded emergence times for *E. civile*.

Greenhouse studies were conducted to see if *Enallagma civile* emergence times were different under closely monitored conditions. Juveniles were reared to adults from eggs that were brought back from playa plants. Daily greenhouse temperatures were recorded using an Onset[c] data logger (Figure 4) and an average greenhouse temperatures were calculated (Table 3). From Table , the total degree days for *Enallagma civile* were calculated. This calculated number was 567.07 days. In order to compare the total degree days of greenhouse reared damselflies to the samples taken from Playa 2, maximum and mean daily temperatures along with precipitation were acquired (Table 2) (National Weather Service). From these temperatures, the total degree days were calculated for the first group of *Enallagma civile* that emerged from Playa 2. The total degree days for E. civile in Playa 2 was 600.8 days and it occurred in twenty-one days.

Secondary Production

Head width gave a good description of the *Enallagma civile* nymphal dry weigth. There was a significant regression between head capsule width and dry weight. In fact, head width accounts for 81.45% of the variation: Ln(head capsule width(mm))=0.4083(Ln(dry weight(mg))+1.503) (r^2 =0.8145, p<0.0001, N=39). Figure 6 gives a clear illustration of this relationship.

Enallagma civile plays an important role in the playa food web. This species has a mean standing stock biomass estimated to be 15.6 mg/m^2 (Table 7). Productivity for this damselfly in its juvenile state is 66.8 mg/m^2 (Table 7) or .0668 g/m^2. The Cohort Production Interval (CPI) was determined to be twenty-one days through field observations at the playa in Amarillo and greenhouse rearing of *Enallagma civile*. Two other insects have had their secondary productivity determined from the playas in the Texas panhandle. *Tropisternus lateralis nimbatus* (Say) and *Callibaetis floridanus* (Banks) were studied for Master's Degree studies. *T. lateralis* is commonly known as a water scavenger beetle and is a predator in playa lakes. It had a secondary productivity of 1.86 g/m^2, a mean standing stock biomass of 0.0819g/m^2, and a Cohort Production Interval of 14 days (Cook 1997). *C. floridanus* is a mayfly that is herbivorous and feeds on algae, diatoms and plant epidermis (Anderson 1998). It had a secondary productivity of 11.7 g/m^2, a mean standing stock biomass of 0.199 g/m^2, and a CPI of 324 days (Anderson 1998). The secondary productivity results were based on a .25 year scale because that is the average amount of time these playas were filled. In addition, these two organisms were studied during the same research period as *Enallagma civile*. Secondary productivity for *E. civile* is lower than for these two organisms.

CHAPTER 6

CONCLUSIONS

This study was conducted to describe the life history of *Enallagma civile* and the other Odonates that inhabit playa habitats in the Southern High Plains of Texas. It was learned that *Enallagma civile* has a low secondary production estimate of 66.8 mg/m^2. It was also determined that this species, *Enallagma civile*, had a developmental time of approximately 21 days in a playa setting. Another important fact was that *E. civile* was the earliest colonizer of all of the Odonate species studied. It was recorded in the playa at least one week earlier than all of the other Odonates.

Odonate populations in the playa continued to increase in size throughout the study. Some populations grew more quickly than others. For instance, the damselfly, *Lestes disjunctus*, had the population that grew the slowest. Its average population estimate per m^2 changed from 0 to approximately 3 in an eight-week time period. On the opposite end of the spectrum, the damselfly, *Enallagma civile*, had an average population estimate per m^2 which increased in size from 2 to approximately 670 naiads in the same eight-week time period.

When the playa began to lose water and thus dwindled in size, the Odonate populations all had significant decreases in size. The naiads either became prey for another organism, emerged or died due to lack of water or lack of food. None of the species in this study were able to continue increases in their population sizes during this time. The period after this drought is what is unique. Some of the species continued to have numbers that dwindled, while others maintained relatively similar amounts of naiads. One species, *Anax junius*, actually had a population explosion after the drought when the playa began to refill close to the beginning of September.

During the course of this study, much was learned about the niches that Odonates occupy in a playa. The populations of some prominent dragonfly species were studied and their quantities were estimated for different periods during one season. Sizes of head capsules were studied in an effort to determine the development of Odonate populations over a period of time. In addition, field sampling showed high points in population sizes and trends in growth. Research was conducted of the life histories of Odonates and a lot of information was gained about the productivity of dragonflies. This study was a valuable proponent to the collection of information available about playa habitats.

Figure 1. The playa lakes region of the United States (Texas Parks and Wildlife 10).

Figure 2. The Ogallala aquifer and the states below which it exists (Opie xii).

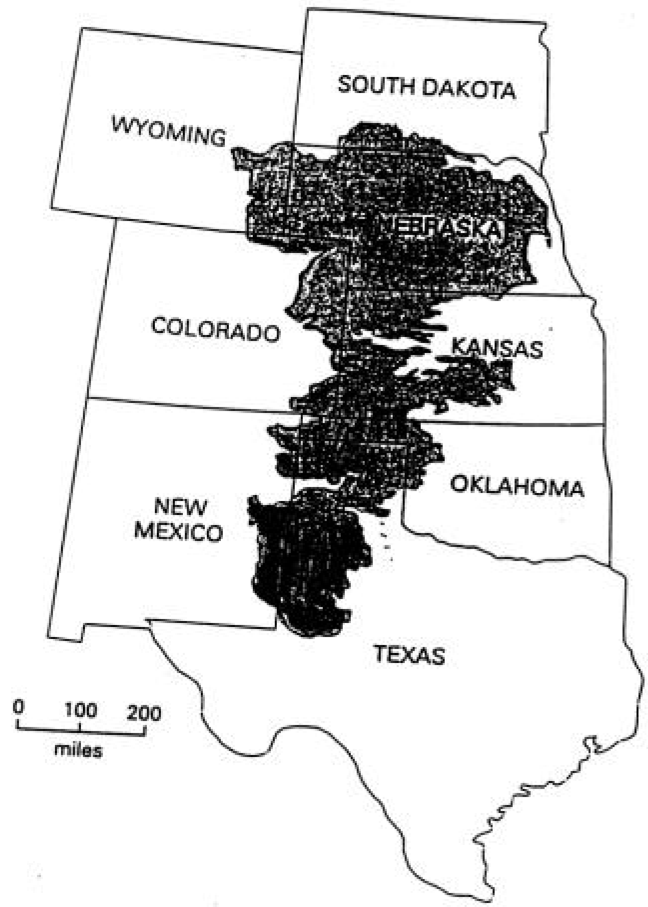

Figure 3. The distribution of *Enallagma civile* in the Western United States (Garrison 99).

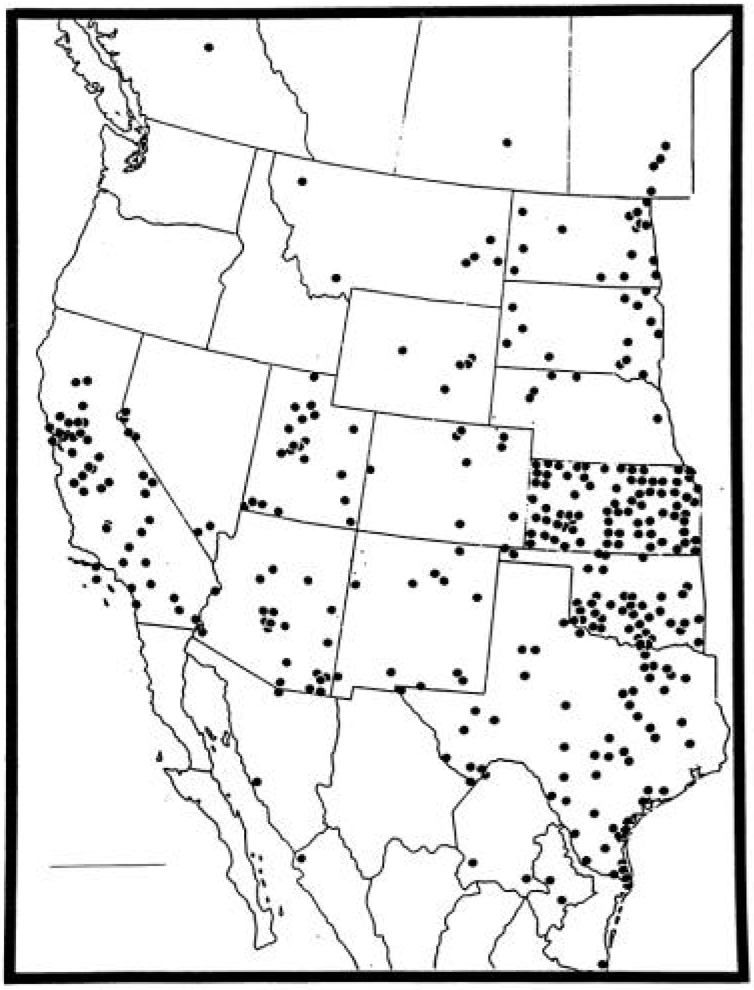

Figure 4. Data logger temperatures from greenhouse studies.

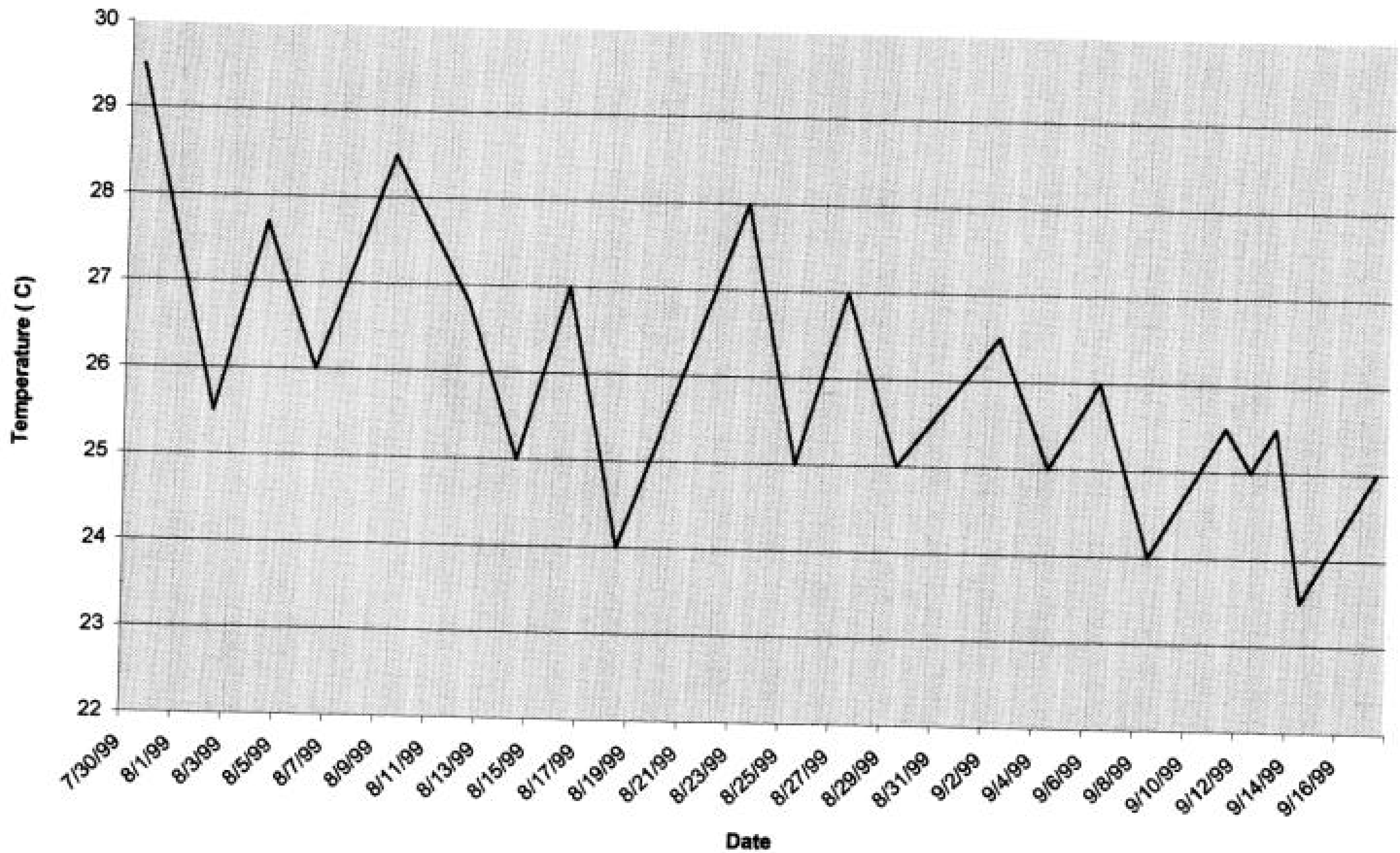

Figure 5. Aquatic dip net and plywood frame used for depletion samples.

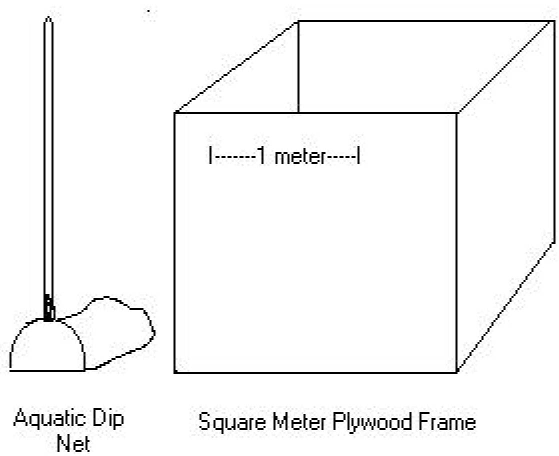

Figure 6. Dry weight versus head width of *Enallagma civile*.

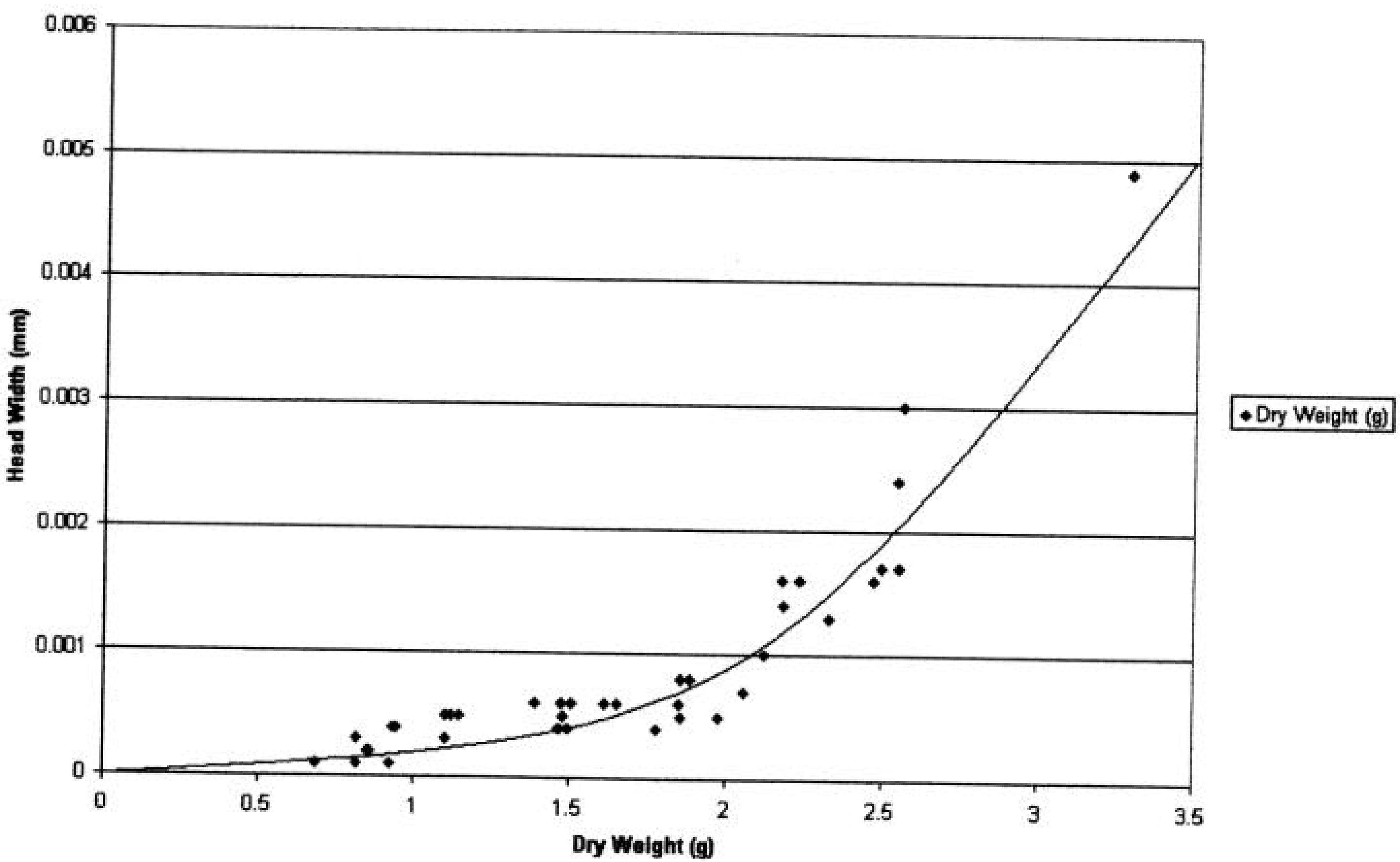

Figure 7. Average population estimate per square meter for *Enallagma civile*.

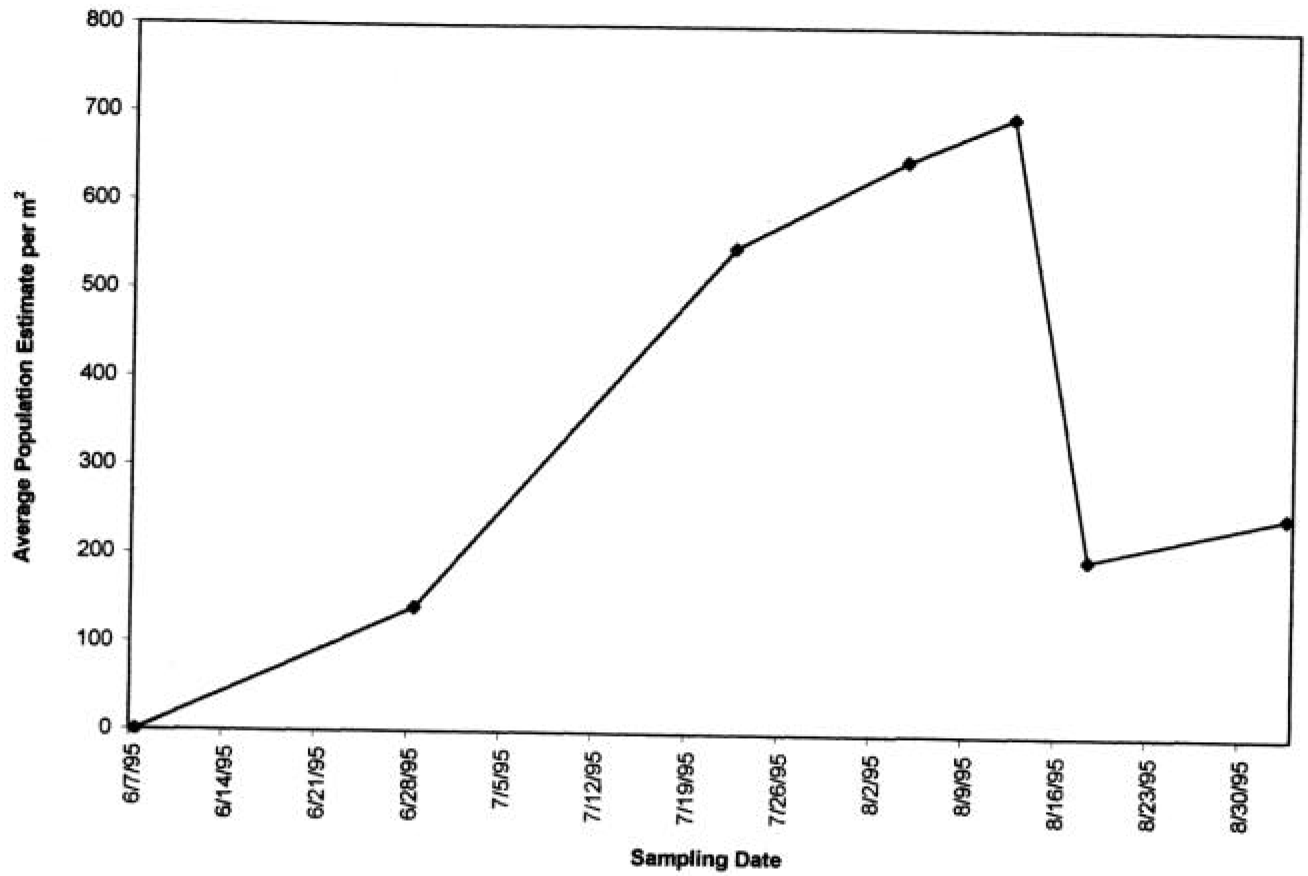

Figure 8. Average population estimates per square meter for Odonates.

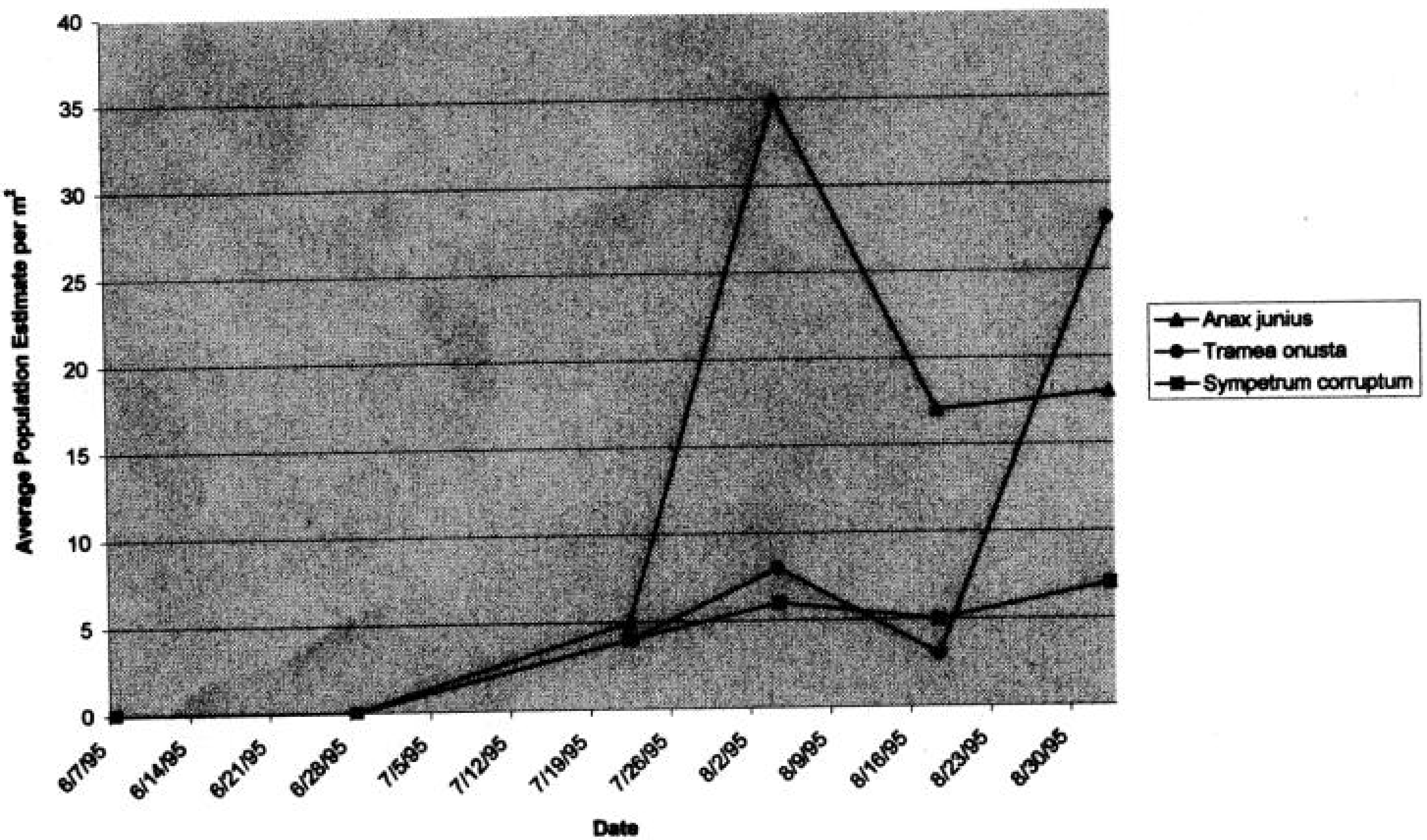

Figure 9. Average nymphal density from depletion samples for *Lestes disjunctus*.

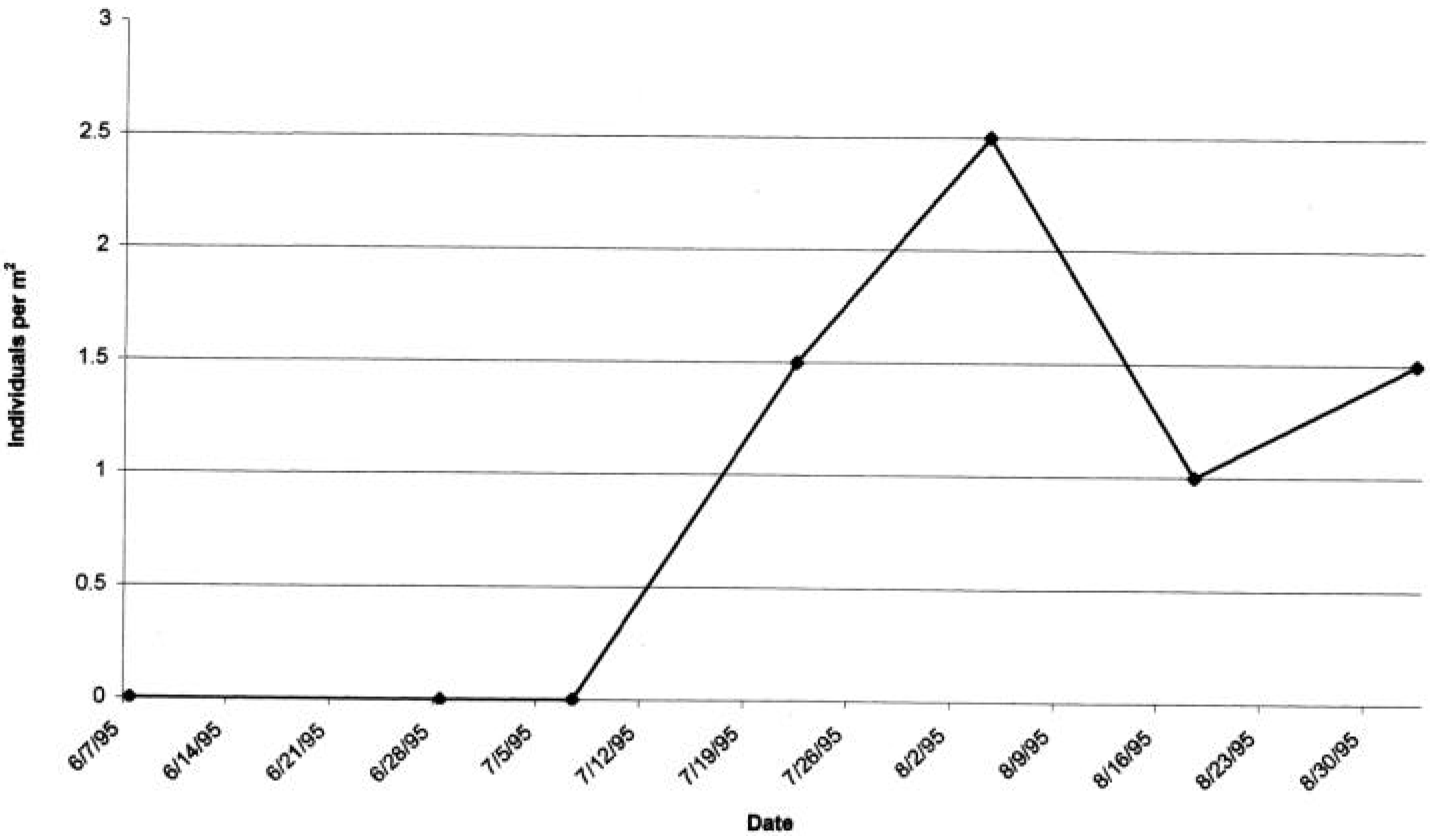

Figure 10. Average nymphal density from depletion samples for *Enallagma civile*.

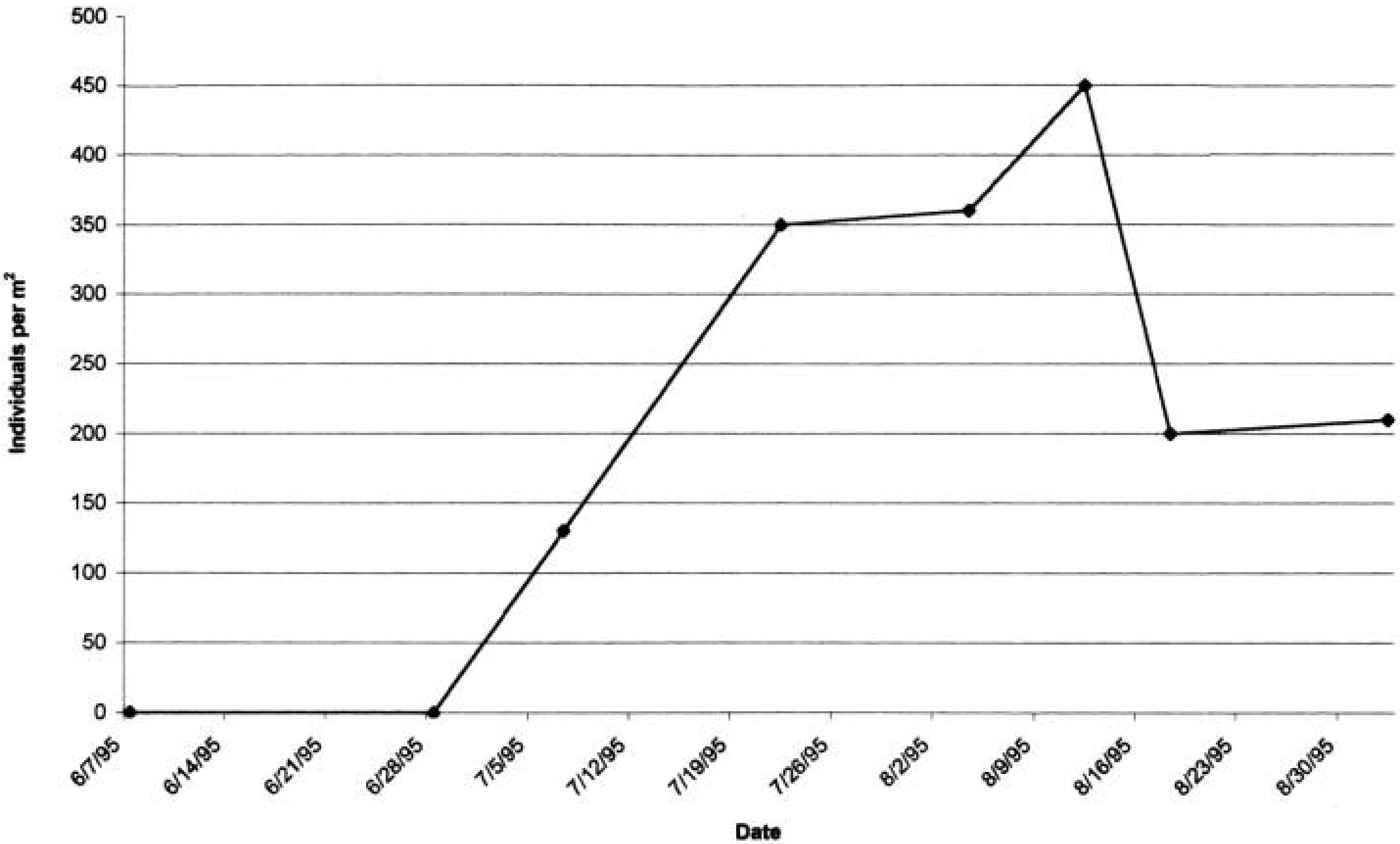

Figure 11. Average nymphal density from depletion samples for *Anax junius*.

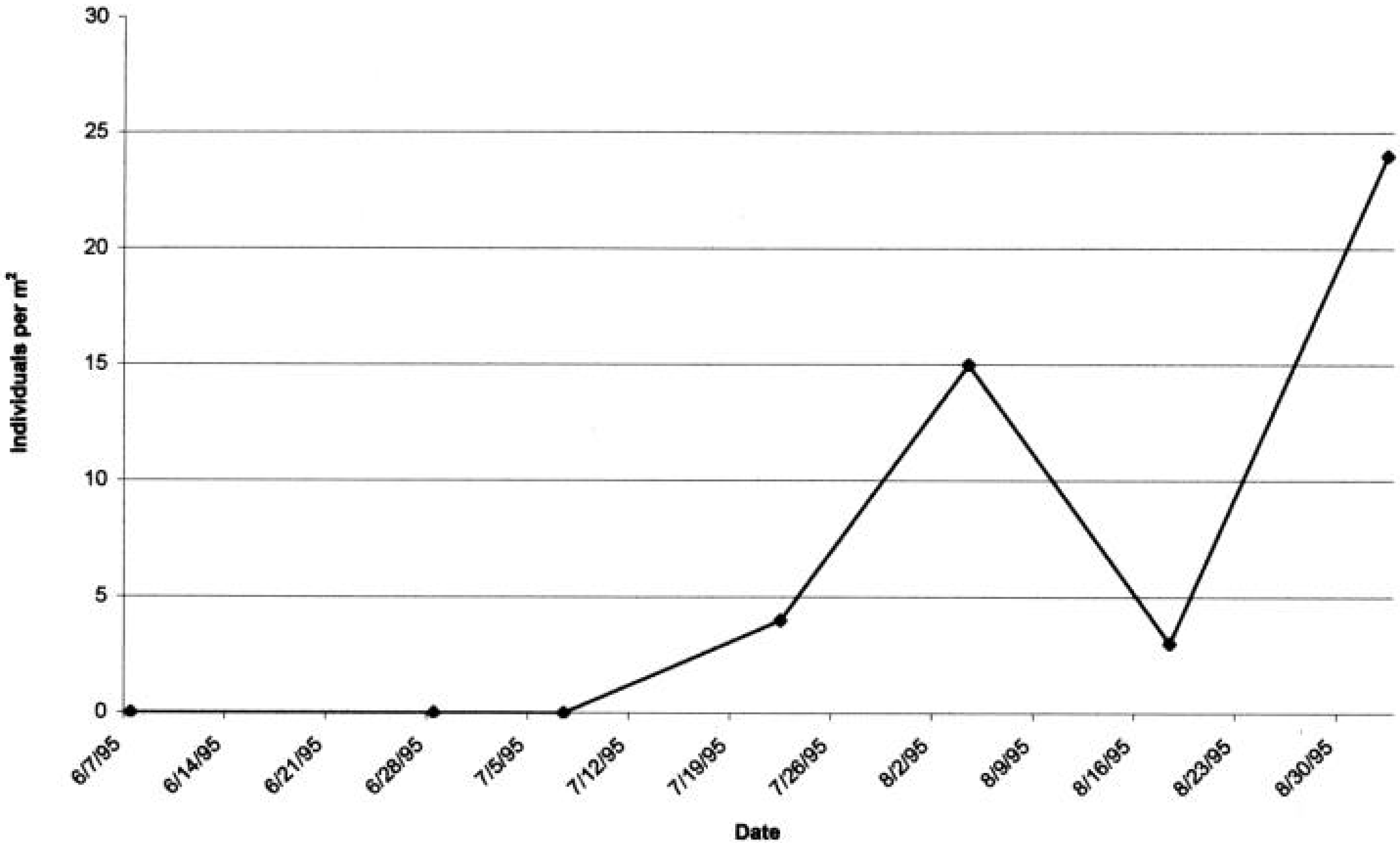

Figure 12. Average nymphal density from depletion samples for *Sympetrum corruptum*.

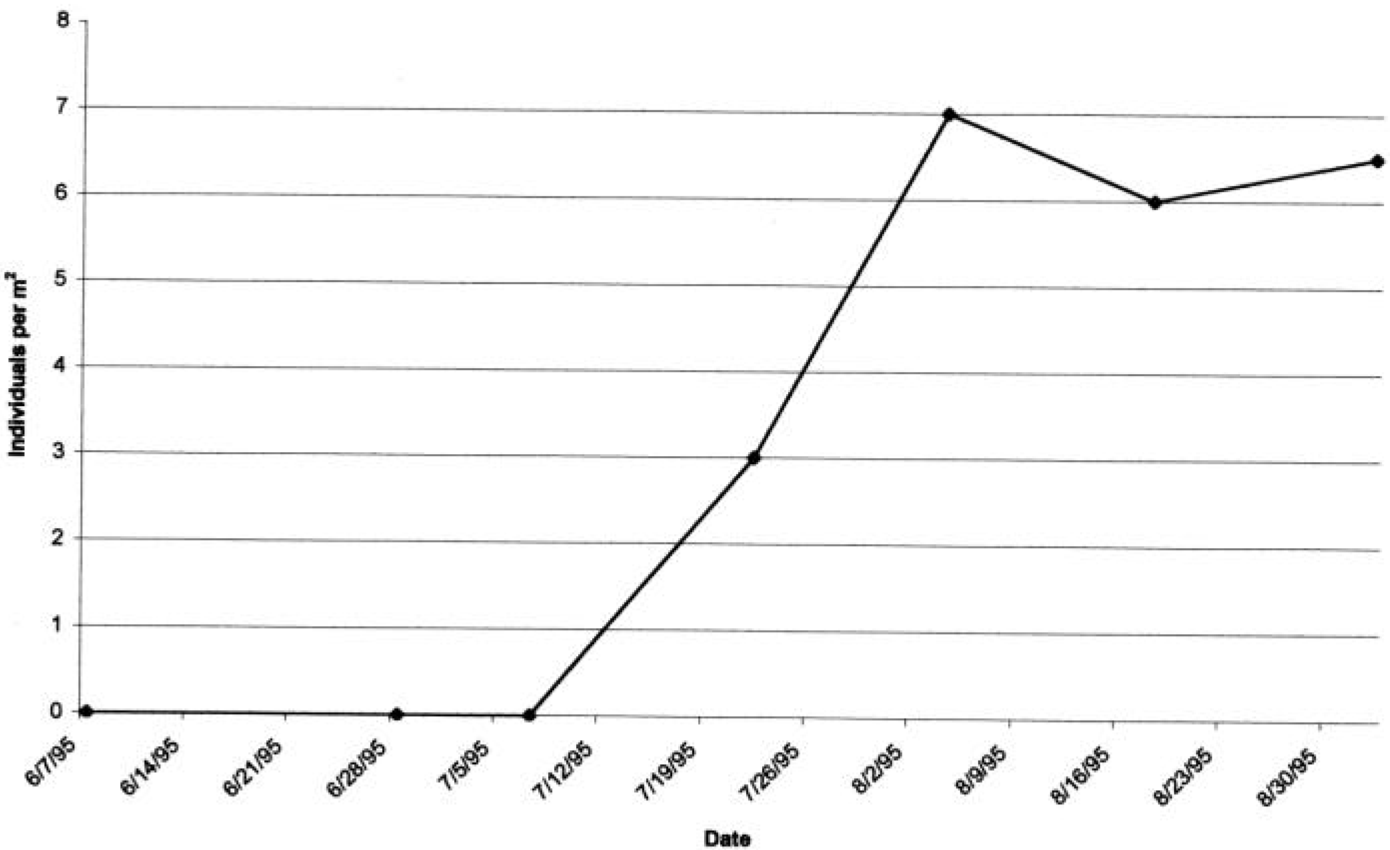

Figure 13. Average nymphal density from depletion samples for *Tramea onusta*.

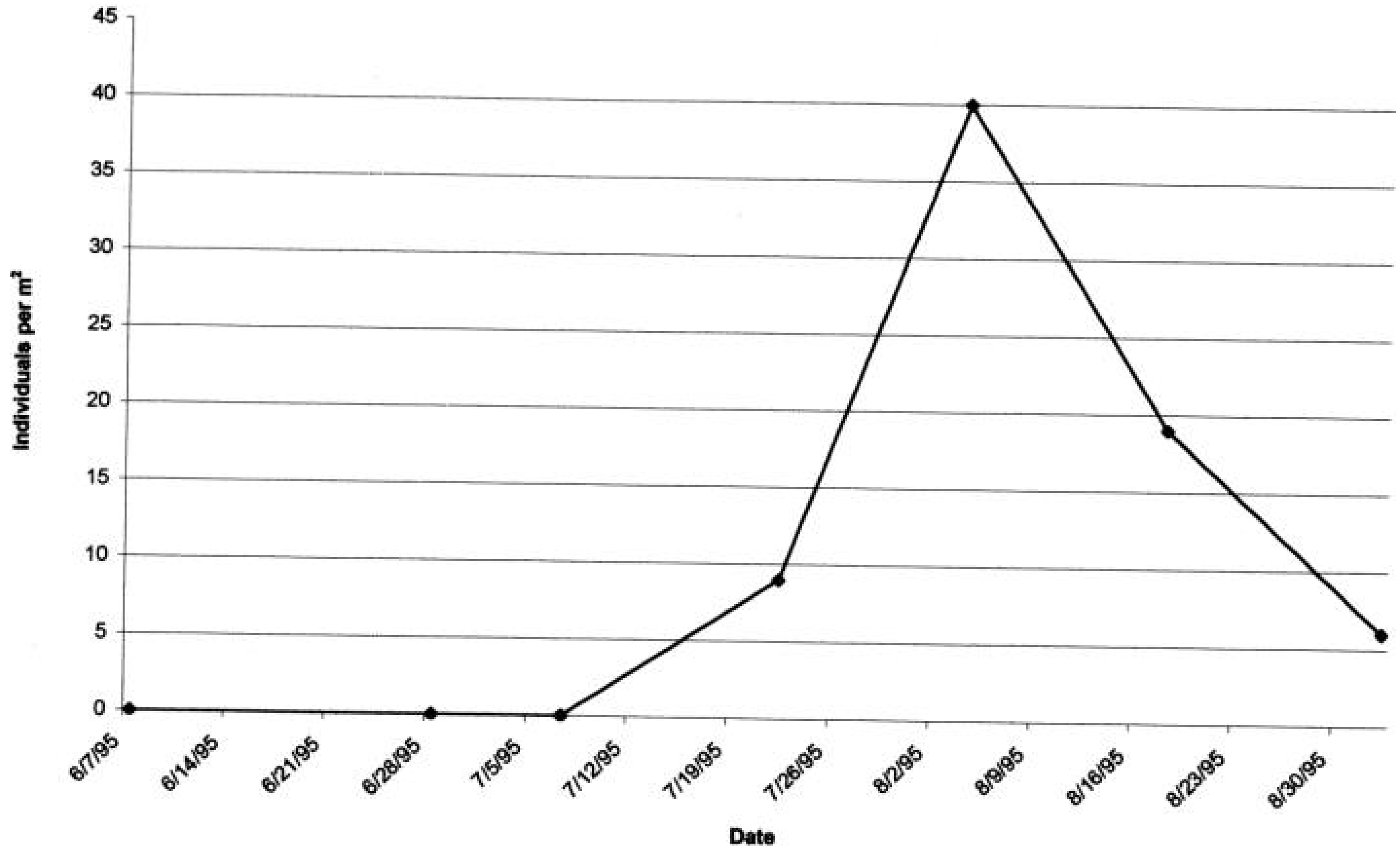

Figure 14. Size frequency distribution by date for Enallagma civile.

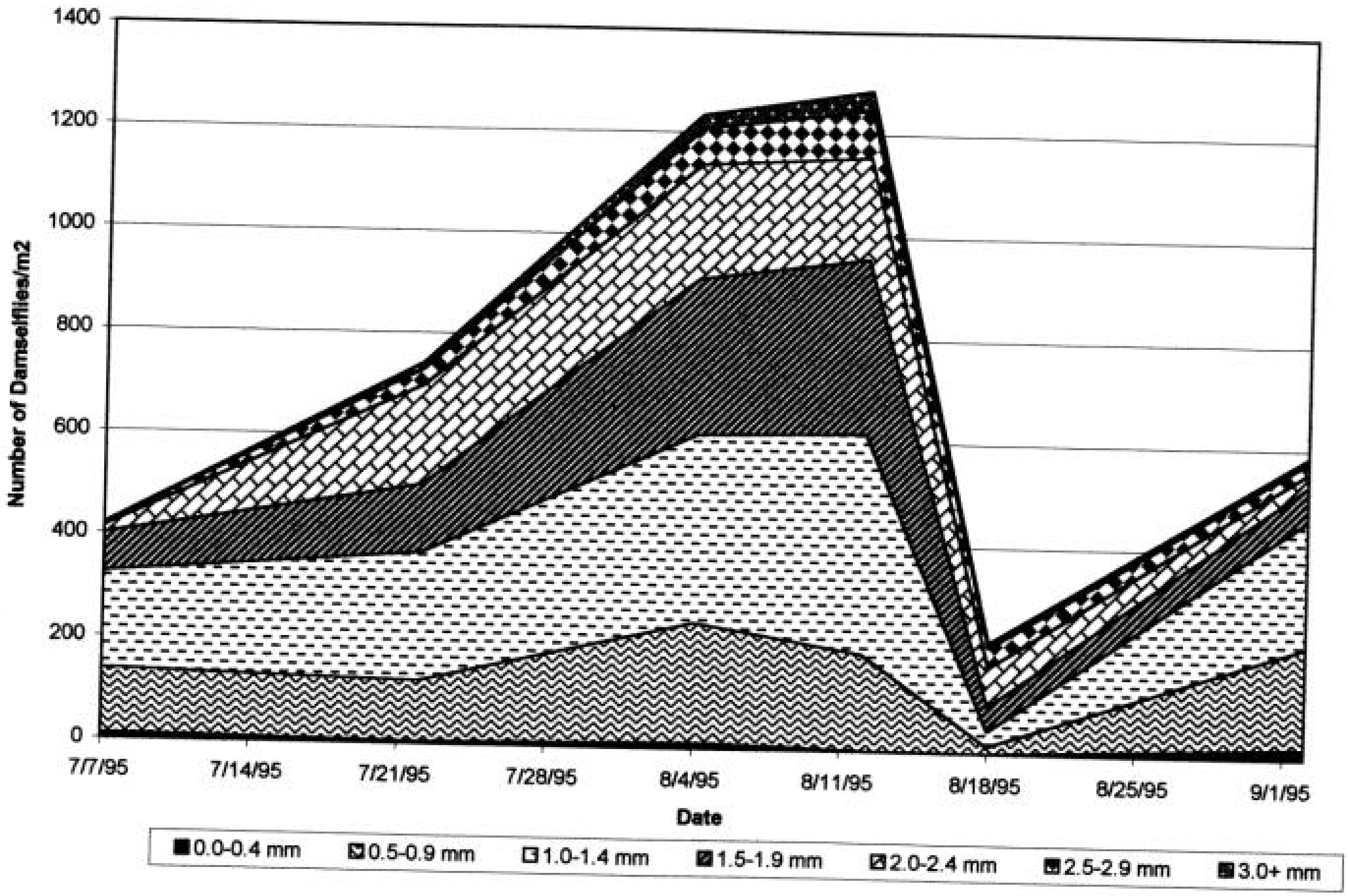

Figure 15. Study location (Kennedy et al. 1996).

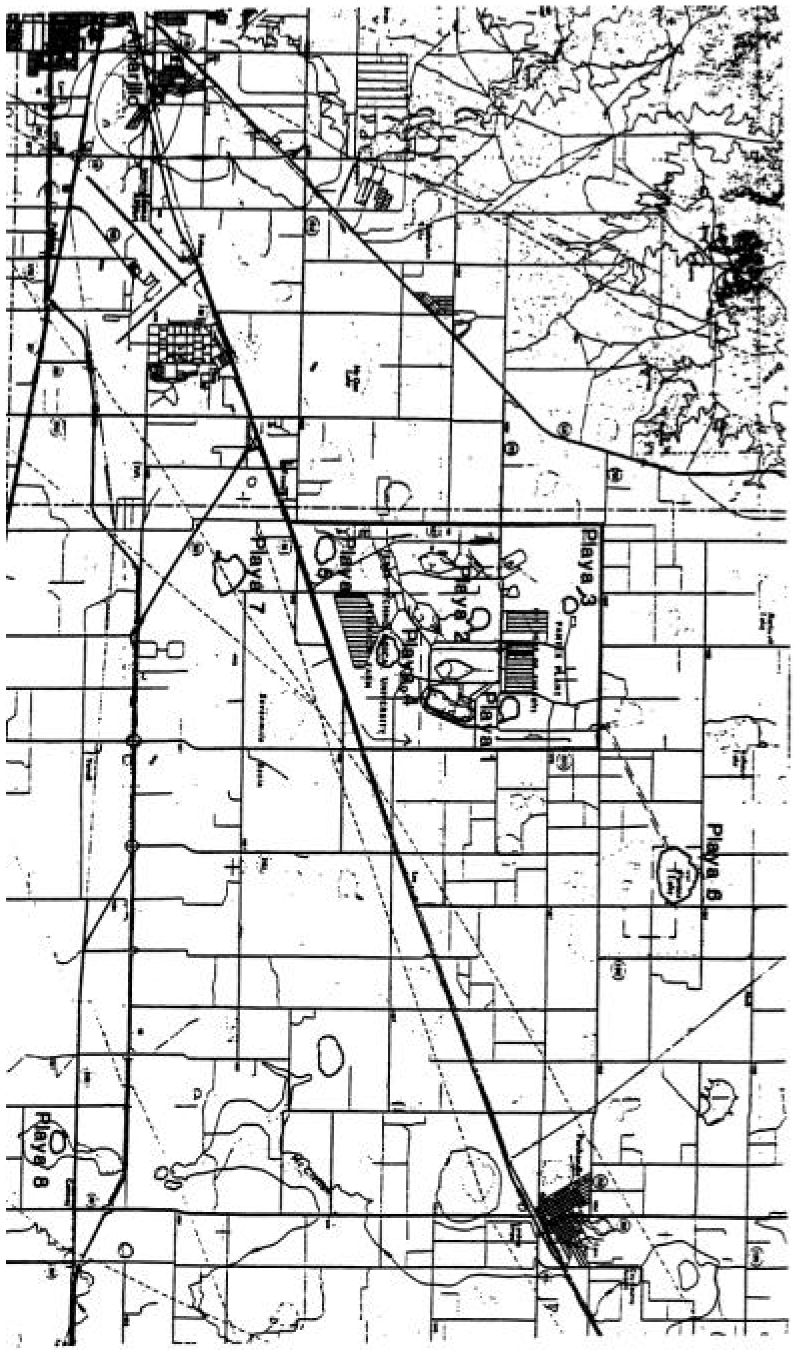

Figure 16. The greenhouse enclosure used for rearing studies.

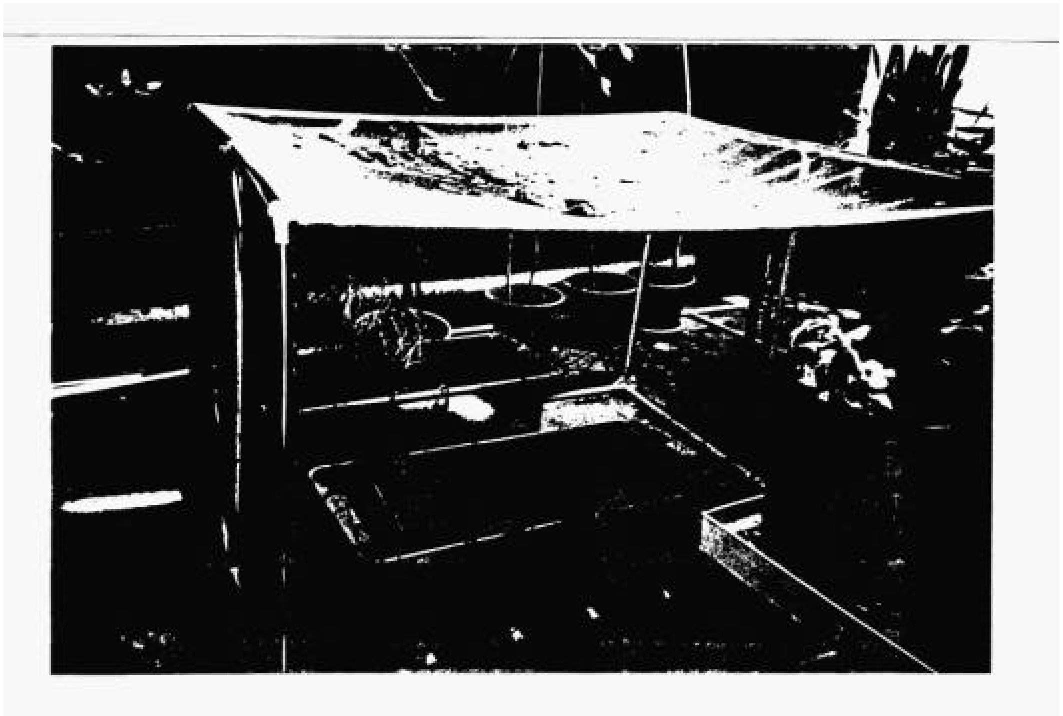

Table 1. Average water quality measurements of Playa 2's wet cycle in 1995 (Anderson 1998).

	11-Jun-1995	8-Jun-1995	4-Aug-1995	2-Sep-1995	Playa Dry	30-Sep-1995
Temperature	14.90	22.00	21.50	18.50		16.80
Dissolved Oxygen (mg/L)	1.40	0.80	0.90	1.30		3.80
pH	7.10	6.80	7.00	7.30		7.10
Chl a (mg/m3)	0.50	13.20	31.40	8.20		10.30
Turbidity (NTU)	69.50	10.30	13.10	14.10		128.30
Conductivity (umho)	NA	242.00	270.00	343.00		212.00

Table 2. Maximum and minimum temperatures and precipitation of Playa 2's wet cycle in 1995 (National Weather Service).

Temperature (°C)				Precip.		Temperature (°C)				Precip.
Date	**Max**	**Min**	**Mean**	**(inches)**		**Date**	**Max**	**Min**	**Mean**	**(inches)**
29-May-1995	16.1	10	13.1	1.1		17-Jul-95	27.8	18.3	23.1	0.02
30-May-1995	23.9	9.4	16.7	0.68		18-Jul-95	23.3	17.8	20.6	0.14
31-May-1995	24.4	10.6	17.5	T		19-Jul-95	31.7	17.8	24.7	T
1-Jun-1995	26.7	12.2	19.4			20-Jul-95	31.1	19.4	25.3	T
2-Jun-1995	26.7	14.4	20.6	0.18		21-Jul-95	33.9	18.9	26.4	0.03
3-Jun-1995	20.6	13.9	17.2	0.64		22-Jul-95	35	17.8	26.4	0.04
4-Jun-1995	24.4	13.3	18.9	T		23-Jul-95	33.3	17.2	25.3	0.17
5-Jun-1995	26.1	13.3	19.7	0.02		24-Jul-95	32.2	14.4	23.3	
6-Jun-1995	33.9	14.4	24.2			25-Jul-95	36.7	17.2	26.9	
7-Jun-1995	30	12.8	21.4			26-Jul-95	37.2	18.9	28.1	
8-Jun-1995	31.7	17.2	24.4			27-Jul-95	40	20	30	
9-Jun-1995	27.8	17.8	22.8			28-Jul-95	38.9	18.9	28.9	
10-Jun-1995	17.8	10	13.9	0.06		29-Jul-95	37.2	18.3	27.8	
11-Jun-1995	23.3	9.4	16.4			30-Jul-95	31.1	20	25.6	
12-Jun-1995	30.6	11.7	21.1			31-Jul-95	30.6	16.7	23.6	0.02
13-Jun-1995	34.4	16.1	25.3			1-Aug-95	20.6	14.4	17.5	T
14-Jun-1995	36.7	17.2	26.9			2-Aug-95	23.9	16.7	20.3	T
15-Jun-1995	33.3	17.2	25.3			3-Aug-95	31.1	17.2	24.2	
16-Jun-1995	30.6	15.6	23.1			4-Aug-95	31.1	17.8	24.4	
17-Jun-1995	26.7	15.6	21.1			5-Aug-95	34.4	18.3	26.4	0.2
18-Jun-1995	27.8	17.2	22.5			6-Aug-95	35.6	16.1	25.8	
19-Jun-1995	30	16.7	23.3			7-Aug-95	36.7	20.6	28.6	
20-Jun-1995	31.1	17.2	24.2			8-Aug-95	35.6	20	27.8	
21-Jun-1995	31.1	17.2	24.2	0.06		9-Aug-95	35	22.8	28.9	
22-Jun-1995	31.7	13.9	22.8			10-Aug-95	35	18.9	26.9	
23-Jun-1995	31.7	13.3	22.5	0.48		11-Aug-95	35.6	18.3	26.9	
24-Jun-1995	26.7	14.4	20.6	T		12-Aug-95	36.1	18.9	27.5	
25-Jun-1995	28.3	13.9	21.1	T		13-Aug-95	35.6	18.3	26.9	
26-Jun-1995	30.6	12.8	21.7	1.12		14-Aug-95	33.3	18.9	26.1	1.95
27-Jun-1995	28.9	12.8	20.8			15-Aug-95	28.3	18.3	23.3	0.03
28-Jun-1995	32.8	16.7	24.7	0.14		16-Aug-95	31.7	19.4	25.6	
29-Jun-1995	22.2	14.4	18.3	0.01		17-Aug-95	32.8	21.1	26.9	
30-Jun-1995	23.3	13.3	18.3			18-Aug-95	32.8	17.8	25.3	
1-Jul-1995	27.2	13.9	20.6	1.22		19-Aug-95	31.7	18.3	25	
2-Jul-1995	30	14.4	22.2	0.26		20-Aug-95	32.2	18.9	25.6	
3-Jul-1995	32.8	15.6	24.2			21-Aug-95	32.8	17.8	25.3	
4-Jul-1995	27.8	15	21.4			22-Aug-95	32.2	18.3	25.3	
5-Jul-1995	29.4	11.7	20.6			23-Aug-95	31.7	17.8	24.7	
6-Jul-1995	31.7	15.6	23.6			24-Aug-95	32.2	17.8	25	
7-Jul-1995	32.8	17.8	25.3			25-Aug-95	33.3	18.9	26.1	
8-Jul-1995	33.9	17.2	25.6			26-Aug-95	33.3	18.9	26.1	

9-Jul-1995	34.4	18.3	26.4			27-Aug-95	33.3	17.8	25.6	
10-Jul-1995	36.1	17.2	26.7			28-Aug-95	33.3	17.8	25.6	
11-Jul-1995	36.1	18.9	27.5			29-Aug-95	35	19.4	27.2	
12-Jul-1995	36.1	17.8	26.9			30-Aug-95	35.6	20.6	28.1	
13-Jul-1995	33.9	18.9	26.4			31-Aug-95	34.4	20	27.2	T
14-Jul-1995	33.9	18.9	26.4			1-Sep-95	34.4	17.8	26.1	
15-Jul-1995	29.4	18.9	24.2	T		2-Sep-95	35	16.1	25.6	
16-Jul-1995	32.2	17.8	25	0.95						

Table 3. Degree days for *Enallagma civile* reared in a greenhouse.

Date	Ave. Temp. (^{o}C)	Min. Temp. (^{o}C)	Max. Temp. (^{o}C)	Degree Days
7/31/99	27.97	25.61	29.56	27.97
8/1/99	26.88	26.48	27.37	26.88
8/2/99	26.71	26.31	27.19	26.71
8/3/99	27.11	26.66	27.73	27.11
8/4/99	26.73	26.13	27.19	26.73
8/5/99	26.76	26.31	27.02	26.76
8/6/99	26.7	25.96	27.37	26.7
8/7/99	27.59	27.02	28.09	27.59
8/8/99	27.86	27.37	28.46	27.86
8/9/99	28.05	27.37	28.64	28.05
8/10/99	27.94	27.37	28.69	27.94
8/11/99	28.08	27.55	28.64	28.08
8/12/99	27.93	27.37	28.46	27.93
8/13/99	27.83	27.55	28.09	27.83
8/14/99	26.88	25.96	27.91	26.88
8/15/99	26.68	25.96	27.19	26.68
8/16/99	25.84	25.27	26.84	25.84
8/17/99	25.11	24.57	25.44	25.11
8/18/99	26.03	25.44	26.66	26.03
8/19/99	26.87	26.31	27.19	26.87
8/20/99	25.52	25.09	27.02	25.52
			Total:	**567.07**

Table 4. Head width (mm) and dry weight (g) for *Enallagma civile*.

Head Width (mm)	Dry Weight (g)
0.68354	0.0001
0.816121	0.0001
0.816121	0.0003
0.851385	0.0002
0.856423	0.0002
0.92152	0.0001
0.93199	0.0004
0.942065	0.0004
1.09824	0.0005
1.09873	0.0003
1.11839	0.0005
1.14358	0.0005
1.38539	0.0006
1.46599	0.0004
1.46835	0.0004
1.47607	0.0006
1.48111	0.0005
1.49622	0.0004
1.5063	0.0006
1.61209	0.0006
1.65063	0.0006
1.77834	0.0004
1.84887	0.0006
1.8539	0.0005
1.8539	0.0008
1.88413	0.0008
1.97468	0.0005
2.05542	0.0007
2.12091	0.001
2.17632	0.0016
2.18136	0.0014
2.23174	0.0016
2.32746	0.0013
2.47089	0.0016
2.4962	0.0017
2.54912	0.0024
2.55416	0.0017
2.56423	0.003
3.28866	0.0049

Table 5. Head capsule widths for *Enallagma civile*.

Date	Depletion	Zone	Maximum (mm)	Minimum (mm)	# Measured
7-Jul-95	1	e	2.57772	0.95614	30
7-Jul-95	1	sw	1.94819	0.83420	60
7-Jul-95	1-d	e	1.88384	0.64647	19
7-Jul-95	1-b	e	2.27638	0.61307	40
7-Jul-95	4	w	1.83249	0.86294	5
7-Jul-95	3-b	w	2.05076	0.69036	30
7-Jul-95	2c	sw	2.42282	0.65101	29
7-Jul-95	3	w	1.67114	0.76510	9
7-Jul-95	2b	sw	2.90970	0.60870	133
7-Jul-95	1c	e	1.90604	0.93960	10
22-Jul-95	2	w	2.51759	0.97487	24
22-Jul-95	3	e	2.58376	0.60406	138
22-Jul-95	1	n	3.14000	0.54667	94
22-Jul-95	3	w	2.30000	0.66667	24
22-Jul-95	1	e	3.26846	0.35571	208
22-Jul-95	4	w	2.44816	0.54850	29
22-Jul-95	3	n	2.68896	0.90301	26
22-Jul-95	3	e	3.34228	0.48322	21
22-Jul-95	4	n	3.02685	0.88591	15
22-Jul-95	2	n	2.87919	0.88591	23
22-Jul-95	1	e	1.37374	1.37374	1
4-Aug-95	3	w	2.53266	0.77890	32
4-Aug-95	2	sw	2.58521	0.53500	95
4-Aug-95	3	ne	3.22667	0.35333	129
4-Aug-95	4	ne	3.28859	0.42953	78
4-Aug-95	2	w	3.12131	0.67340	49
4-Aug-95	3	sw	2.90909	0.78788	90
12-Aug-95	2	sw	3.22667	0.44667	111
12-Aug-95	4	e	0.84000	0.84000	1
12-Aug-95	2	e	3.20805	0.79866	53
12-Aug-95	4	e	3.21212	0.71381	28
12-Aug-95	3	e	2.90909	0.74748	50
18-Aug-95	1	sw	3.05333	0.50667	111
18-Aug-95	4	sw	none	none	none
2-Sep-95	3-b	w	3.21886	0.47811	64
2-Sep-95	3-a	w	1.15152	1.15152	1
2-Sep-95	2-b	e	3.34007	0.65320	47
2-Sep-95	2	w	2.25589	0.60606	19
2-Sep-95	2-c	e	2.64646	1.11785	9
2-Sep-95	2-d	e	2.93603	0.76094	8
2-Sep-95	1	w	3.23232	0.33670	41

Table 6. Counts of five species of Odonates for different sampling dates.

Sampling Date	Number	Species
July 22, 1995	25	*Tramea onusta*
August 4, 1995	49	*Tramea onusta*
August 18, 1995	16	*Tramea onusta*
September 2, 1995	27	*Tramea onusta*
July 22, 1995	11	*Sympetrum corruptum*
August 4, 1995	23	*Sympetrum corruptum*
August 18, 1995	6	*Sympetrum corruptum*
September 2, 1995	11	*Sympetrum corruptum*
July 22, 1995	5	*Lestes disjunctus*
August 4, 1995	6	*Lestes disjunctus*
August 18, 1995	1	*Lestes disjunctus*
September 2, 1995	5	*Lestes disjunctus*
July 22, 1995	8	*Anax junius*
August 4, 1995	32	*Anax junius*
August 18, 1995	3	*Anax junius*
September 2, 1995	80	*Anax junius*
July 22, 1995	632	*Enallagma civile*
August 4, 1995	1262	*Enallagma civile*
August 12, 1995	1313	*Enallagma civile*
August 18, 1995	229	*Enallagma civile*
September 2, 1995	608	*Enallagma civile*

Table 7. Production calculations for Enallagma civile from the Southern High Plains of Texas June 7, 1995—September 2, 1995.

Size Class (mm)	n, no./m^2	DM, mg	B, mg/m^2	delta in n	DM at loss	DM loss	x number of size classes (7), mg/m^{2*}
0-0.49	42	1.622 x 10^-5	6.8124 x 10^-4	-864	6.401 x 10^-5	-0.0553	0
.5-.99	906	1.118 x 10^-4	0.1012908	-623	2.184 x 10^-4	-0.1361	0
1.0-1.49	1529	3.250 x 10^-4	0.496925	541	5.3215 x 10^-4	0.2879	2.0153
1.5-1.99	988	7.393 x 10^-4	0.7304284	375	0.00121965	0.4574	3.2018
2.0-2.49	613	0.0017	1.0421	340	0.00195	0.663	4.641
2.5-2.99	273	0.0022	0.6006	181	0.0028	0.5068	3.5476
3.0-3.49	92	0.0034	0.3128	92	0.0034	0.3128	2.1896
							Total=15.5953

Total Production=15.5953 mg/m^2 x (90 days/21 days)=**66.837 mg/m^2 or .066837g/m^2**

n, no./m^2=Number present per square meter of each size class
DM, mg=Mean dry mass (in milligrams)of individuals of each size class
B, mg/m^2=Total mean annual biomass for each size class
delta in n=Change in number of individuals present between each size class
DM at loss=Mean dry mass of individuals of each instar when lost from the population (calculated as DM^x + DM^(x+1)/2)
DM loss=Total dry mass (milligrams) lost with each instar
x number of size classes(7), mg/m^2=Dry mass loss x the number of size classes gives mean annual production for each instar
*=with negative numbers set to zero

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